Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Spectrum Horizons	)	ET Docket No. 18-21
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	)	

COMMENTS OF TERAMETRIX, A DIVISION OF LUNA INNOVATIONS, INC.

TeraMetrix, a Division of Luna Innovations, Inc., (TeraMetrix), is pleased to provide the Federal Communications Commission (FCC) comments on the Notice of Proposed Rule Making (NPRM) for "Spectrum Horizons" seeking to authorize telecommunications operations in the bands between 95 GHz to 3,000 GHz.

TeraMetrix is based in Ann Arbor, Michigan, and is a division of Luna Innovations, Inc. (NASDAQ LUNA) of Roanoke, Virginia. TeraMetrix employs approximately 25 people in its Ann Arbor factory. TeraMetrix markets and sells commercial time domain terahertz instrumentation for industrial process monitoring and control; non-destructive imaging; and research and development spectroscopy. Previously, as Picometrix, TeraMetrix introduced the world's first time domain terahertz spectroscopy system in 1999, the "T-Ray 2000." Since 2012, our T-Ray 5000 series of "T-Gauge" instrumentation has been deployed worldwide by industry, academia, the U.S. D.O.D., and NASA.

TeraMetrix's T-Ray 5000 series of "T-Gauge" instrumentation is used for industrial on-line factory process monitoring and control by measuring multi-layer thickness of extruded plastics; multi-layer thicknesses of paints (including wet paint); basis weight; density; delamination and moisture. TeraMetrix's time domain terahertz gauges are deployed worldwide in factories that make tires, rubber, building products, paper, plastic pipe, coated steel pipe, blow

molded bottles, aircraft coatings, fuel tanks, and many other products. As a non destructive imaging device, TeraMetrix imagers are/have been used to image the Space Shuttle external tank, the Space Shuttle thermal protection system, Orion spacecraft thermal protection system, military aircraft coatings, military ship coatings, radomes, food, pharmaceuticals, and other products.

NPRM FCC 18-17 paragraph 60 states:

> "The shorter wavelengths of frequencies above 95 GHz may be particularly well suited for non-communication sensing applications such as spectroscopy and imaging. For example, studies have shown that specific molecular rotation, vibration, liberation of molecules, and molecular aggregates occur in the terahertz band, which enables a large variety of applications for the detection and/or identification of molecules in diverse areas. Other potential applications of terahertz technology include detection of drugs and explosives, detection of cancerous tissue, as well as materials analysis and quality control."

TeraMetrix concurs with the commercial potential for the use of the 95 GHz to 3,000 GHz band for industrial quality control; industrial process monitoring and control; and scientific research and development. Time domain terahertz non destructive evaluation[1,2] and industrial process monitoring[3,4] is a well developed commercial field with nearly 20 years of established industrial, scientific, and military applications that span an even greater range than as noted in NPRM paragraph 60.

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[1] Daniel M. Mittleman, "Twenty Years of Terahertz Imaging," Optics Express, Vol. 26, Issue 8, pp 9417-9431 (2018),

[2] Peiponen, Zeitler, and Kwata-GonoKami, ed. "Terahertz Spectroscopy and Imaging, " Springer, 2013.

[3] D. Saeedkia "Handbook of Terahertz Technology for Imaging, Sensing, and Communications," 1st Ed. Woodhead Publishing, 2013.

[4] Michael Theuer, " Terahertz Time-Domain Spectroscopy Systems for Fundamental and Industrial Applications," Cuvillier Verlag Gottingen, 2009.

TeraMetrix has a strong interest that the current NPRM (and future rule-making) does not produce overly burdensome rules that adversely affect our business or place our company at a competitive disadvantage. While TeraMetrix believes it is competitive in the market for time domain terahertz process monitoring equipment worldwide, significant competing manufacturers are foreign (and are not subject to FCC rules in their home markets). These competitors are based in Canada, United Kingdom, Germany, Japan, Austria, and Lithuania.

NPRM FCC 18-17 footnote 150 states: "Terahertz spectroscopy is a technique in which the properties of a material are probed with short pulses of terahertz radiation."

As a point of clarification, TeraMetrix uses the term "time domain terahertz" in these comments to refer to what others in the literature may refer to as "time domain terahertz spectroscopy," "terahertz time domain spectroscopy," "THz-TDS," "Terahertz Pulsed Spectroscopy," "Terahertz Pulsed Imaging," "T-Rays" or "T-Waves." These all employ a similar type of RF emitter and are equivalent. To be rigorous, TeraMetrix defines "time domain terahertz" to refer to the coherent generation and detection of sub-picosecond electromagnetic transients generated in biased semiconductor devices by femtosecond laser pulses.[5] These pulses are broadband in nature, are not modulate, do not carry information, and lack a center carrier wave in the traditional sense. TeraMetrix believes that this is the specific type of technology referred to as "terahertz spectroscopy" in NPRM FCC 18-17 footnote 150.

While the method of "time-domain terahertz" is widely employed in academia and has been commercialized by TeraMetrix and others, it is critical for the FCC to understand that there are many other potential ways of performing spectroscopy using RF sources in the 95 GHz to 3,000 GHz range. "Time domain terahertz" spectroscopy is only

[5] P. R. Smith, D. H. Auston, and M. C. Nuss, "Subpicosecond photoconducting dipole antennas," *IEEE J. Quant. Elec.*, **24**, 255 (1988).

one very specific implementation of a method that may be used by Industrial Scientific and Medical devices in the band covered by Spectrum Horizons.

A partial list of alternative technologies in the 95 GHz to 3,000 GHz band to "time-domain terahertz" include: tunable continuous wave photomixing, tunable backwards wave oscillators, tunable diode multiplier-mixers, tunable non-linear laser difference frequency mixing, tunable quantum cascade lasers and traditional Fourier Transform Infrared Spectrometers with a blackbody globar. Note that the last three examples are traditionally considered entirely optical technologies, and they do not employ the traditional RF accessories such as antenna and waveguides but rather employ lenses and mirrors. Many of the "terahertz RF" detectors employed for these devices are actually heat sensors such as bolometers. TeraMetrix speculates that many of the manufacturers and users of these "optical" terahertz systems are likely unaware of the FCC's regulatory jurisdiction because they do not consider the emission or use to be RF, but optical. TeraMetrix suggests that each of these alternative methods of "terahertz spectroscopy" (and others) should be evaluated individually on a case by case basis by their manufactures under FCC rules with respect to their own specific technical implementation of their RF source and operation. Not all of these alternative methods may be compliant with current FCC rules and manufactures and users may need to apply for rules making or experimental licenses, as appropriate.

As described in these comments, TeraMetrix holds that its time-domain terahertz instrumentation falls under the current rules for 47 CFR PART 18 "Industrial Scientific and Medical" RF equipment. TeraMetrix has followed the "Manufacturer's Declaration of Conformity" procedure for marketing and selling its time-domain terahertz products.

NPRM FCC 18-17 paragraph 60 states:

> "The Commission also seeks comment on what rules might be most appropriate for ISM operations in the above 95 GHz band. Part 18 of the rules contains the regulations for ISM equipment. ISM equipment is defined as equipment or appliances designed to generate and use locally RF energy for industrial, scientific, medical, domestic or similar purposes, excluding applications in the field of telecommunication. Typical ISM applications are the production of physical, biological, or chemical effects such as heating, ionization of gases, mechanical vibrations, hair removal and acceleration of charged particles. ISM equipment operated within certain designated frequency bands is not subject to emissions limits within those bands. However, emissions from ISM equipment that fall outside of these bands must comply with limits designed to prevent harmful interference to authorized radio services."

TeraMetrix observes that 47 CFR PART 18 already specifically and quantitatively provides rules for operation of ISM devices throughout the 95 GHz to 3,000 GHz spectral region. TeraMetrix observes that although NPRM FCC 18-17 requests comment on 47 CFR PART 18 regarding to operation 95 GHz to 3,000 GHz spectral region, however the NPRM does not propose any specific rules changing 47 CFR PART 18. TeraMetrix is agnostic as to whether more permissive rules between 95 GHz and 3,000 GHz would be beneficial, however TeraMetrix strongly requests that 47 CFR PART 18 not be made more restrictive or burdensome as a substantive commercial instrumentation industry has been operating under the current rules for nearly 20 years.

TeraMetrix observes the following in the current text of 47 CFR PART 18:

47 CFR § 18.107 (a) "Radio frequency (RF) energy. Electromagnetic energy at any frequency in the radio spectrum from 9 kHz to 3 THz (3,000 GHz)."

The plain text reading is that this statement defines the frequency range of the rule, which includes the 95 GHz to 3,000 GHz range. And;

47 CFR § 18.107 (c) "Industrial, scientific, and medical (ISM) equipment. Equipment or appliances designed to generate and use locally RF energy for industrial, scientific, medical, domestic or similar purposes, excluding applications in the field of telecommunication. Typical ISM applications are the production of physical, biological, or chemical effects such as heating, ionization of gases, mechanical vibrations, hair removal and acceleration of charged particles."

TeraMetrix observes that § 18.107 (c) defines ISM equipment very broadly with the only specific restriction of "…excluding application in the field of telecommunication." The term "…Typical…" only references examples of ISM applications without specifically restricting ISM equipment to the applications listed.

47 CFR § 18.301 "Operating frequencies. ISM equipment may be operated on any frequency above 9 kHz except as indicated in § 18.303…." (noting § 18.303 contains no restrictions above 95 GHz). § 18.301 defines certain bands (including bands above 95 GHz at 122.5 GHz and 245.0 GHz at which ISM devices are permitted unlimited radiated energy by § 18.305 (a)) And;

47 CFR § 18.305 (b) "The field strength levels of emissions which lie outside the bands specified in § 18.301, unless otherwise indicated,

shall not exceed the following: …" where the ISM equipment field strength limits for "Any type unless otherwise specified (miscellaneous)." with an operating frequency of "Any non-ISM frequency" with an RF power generated of "Below 500" watts must not have a field strength of more than "15" microvolts/m at "300" meters.

Specifically, because a time domain terahertz emitter has no specific carrier wave and its broad band emission spans the range of 95 GHz to 3,000 GHz, TeraMetrix has interpreted that TeraMetrix time domain terahertz products must meet these established § 18.305 (b) limits at all frequencies at the "Any non-ISM frequency" limit (§ 18.107 (a) from 9 KHz to 3 THz). TeraMetrix has had an independent laboratory certify that in the manufacturer's specified mode of operation of its instrumentation, the RF emission above and below 95 GHz meet the § 18.305 (b) limits at all frequencies. And;

47 CFR § 18.111 (b) "Subject to the exceptions in paragraphs (c) and (d) of this section and irrespective of whether the equipment otherwise complies with the rules in this part, the operator of ISM equipment that causes harmful interference to any authorized radio service shall promptly take whatever steps may be necessary to eliminate the interference."

TeraMetrix does not believe that operating under a non interference rule is a burdensome issue or risk for its time-domain terahertz industrial process monitoring, quality control, non-destructive testing, and research spectroscopy customers. § 18.113, § 18.115 and § 18.117 provide for adequate procedures to document and resolve interference. TeraMetrix notes that in nearly 20 years of operation, TeraMetrix is not aware of its equipment generating any RF interference complaints above or below 95 GHz.

The time domain terahertz instrumentation manufactured by TeraMetrix is for non-consumer ISM purposes. TeraMetrix does not envision any near term consumer applications of time domain terahertz instrumentation. Under 47 § 18.203 "Equipment authorization. (a) Consumer ISM equipment, unless otherwise specified, must be authorized under either the Declaration of Conformity or certification procedure prior to use or marketing…" TeraMetrix holds that since the time domain terahertz instrumentation is non-consumer, 47 CFR § 2.906 requires a "Supplier's Declaration of Conformity." TeraMetrix' equipment has been independently tested to meet § 18.305 (b) limits and TeraMetrix provides a "Suppliers Declaration of Conformity" and TeraMetrix complies with § 18.209 (b) "Identification of Authorized Equipment", § 18.212 "Compliance" information.", and § 18.213 "Information to the User."

NPRM FCC 18-17 paragraph 61 states:

> "The Commission has historically treated RF devices that transmit a radio signal for purposes such as measuring the level of a fluid in a container or for measuring some quantifiable property of a material as Part 15 devices. Due to the modulated transmission of information, the Commission decided that they were best treated as Part 15 low power transmission devices as opposed to Part 18 equipment where RF energy is generated to perform work, such as in an industrial heater or microwave oven. With some applications the distinctions are not as distinct, which has resulted in a case-by-case analysis. For example, magnetic resonance imaging systems subject to Part 18 that use RF energy to stimulate molecules to produce a detectable RF field used to form images of the body have been determined to be subject to Part 18 of the rules. We are aware of interest in using

the spectrum above 95 GHz for devices that use terahertz spectroscopy to analyze material properties and for imaging applications, which could possibly be considered ISM applications…"

TeraMetrix observes that the commission is stating that although certain RF devices may be sold for a clearly industrial, scientific, or medical purpose (e.g. the measurement of a level of a fluid in container), that by precedent and rule certain "industrial, scientific, and medical" devices are regulated under Part 15 rather than Part 18 (despite the title of Part 18).

TeraMetrix observes that the rationale as described in paragraph 61 for creating a distinction between whether an RF device designed for a non-communication purpose falls under Part 15 or Part 18 depends on the specific details of the operation of the transmitter and the communication of information to the subject under test – not the application nor the information derived from the instrument.

TeraMetrix notes that traditionally, microwave and millimeter wave RF instruments used to measure distances such as the level of a fluid in a container used transmitters that have a fundamental oscillator frequency (carrier wave) that must be modulated (pulsed or swept in frequency) such as in frequency modulated continuous wave (FMCW) radar. The FCC holds that in such a system "information is transmitted to the subject under test." This modulation must be kept within the allowed bandwidth of the device and sidebands must be controlled to prevent interference outside of the allowed band. TeraMetrix speculates that, historically, the desire to operate RF measurement devices in the ISM "unlimited power bands" was because it was not technically possible to restrict the transmitter power to the limits of § 18.305 (b) "any non-ISM frequency" and that modulation of the RF was required to make the measurement. This is not the case for time domain terahertz instrumentation.

The wide band RF generated by the emitter used in time-domain terahertz instrumentation does not have a center frequency in the traditional sense of an oscillator, nor is it modulated in any way. No information is communicated from the emitter to the subject under test in any time domain terahertz application (e.g. non-destructive testing imaging, the measurement of coating thickness, the measurement of foam density, etc.). Because the time domain terahertz RF emission is not modulated and does not communicate information, and because TeraMetrix's time-domain terahertz RF instrumentation meet the plain language interpretation of a "Industrial, Scientific, and Medical" device, TeraMetrix holds that the time domain terahertz instrumentation falls under the current scope of 47 CFR PART 18.

The commission notes that certain devices such as an MRI, which typically operates using a sequence of RF pulses to stimulate the emission of radiation at another frequency in order to generate and image of an object are regulated under Part 18, even though it might be argued that the MRI pulse sequence is a modulated of a carrier wave and the transmission of information. TeraMetrix does not hold that consideration of this MRI ambiguity in Part 18 vs. Part 15 classification is necessary to consider time domain terahertz instrumentation as currently regulated under Part 18, since no transmitter modulation occurs and no information is transmitted (so there is no ambiguity such as in MRI).

TeraMetrix concedes that others may have interest in commercializing ISM instrumentation in the 95 GHz to 3,000 GHz range that relies on a modulated carrier wave (i.e. FMCW radars); either within the existing no power limit ISM bands of 122.5 GHz and 245.0 GHz or outside the ISM bands; and that this type of technology does not fall under Part 18 rules. TeraMetrix has no objection to the adoption of unlicensed Part 15 ISM operation within bands in the 95 GHz to 3,000 GHz range as long as it is done in a mutual non-interference basis; and that

such new rule making does not preclude any current use of time domain terahertz in the existing Part 18 rule framework.

NPRM FCC 18-17 paragraph 61 further states:

> "…While the Office of Engineering and Technology currently evaluates applications for devices that use the frequencies above 95 GHz on a case-by-case basis, we note that it has found that some equipment used to detect the presence of powders, solids and liquids inside sealed parcels and envelopes to be ISM equipment subject to Part 18 of the rules"

TeraMetrix observes this statement about "the Office of Engineering and Technology" evaluating "applications for devices that use the frequencies above 95 GHz on a case-by-case basis" may conflict with the concept of the "Suppliers Declaration of Conformity" and is concerned that it represents rule-making with respect to Part 18. Specifically, TeraMetrix interprets that since Part 18 allows the use of a "Suppliers Declaration of Conformity," that it is up to the manufacturer to determine compliance with Part 18. TeraMetrix agrees that if a manufacturer were to determine that their device does not conform with Part 18 as written, then that manufacturer would need to apply for an experimental license and/or petition for rulemaking. However, the text of 47 CFR PART 18 nowhere states that a compliant device that operates above 95 GHz must use the "certification procedure" as opposed to the "declaration of conformity" procedure.

NPRM FCC 18-17 paragraph 62 states:

> "We recognize that the radiated emission limits in Part 18 were originally developed for devices operating at significantly lower frequencies than we are considering here, and seek comment on how that should affect our analysis.

Accordingly, we seek comment on whether changes to these limits are necessary for operation above 95 GHz. Are the limits in Section 18.305 appropriate for these devices?..."

TeraMetrix notes that it has been marketing and selling its time domain terahertz instrumentation under the Part 18 rules, which clearly specify operation from 9 KHz to 3THz (47 CFR § 18.107 (a)) for nearly 20 years. Manufacturers reading the plain text of the rule are unlikely to be aware of the historical genesis of the rule. TeraMetrix strongly requests that any future rule making concurs with time domain terahertz instrumentation being regulated under Part 18. TeraMetrix has no objection to the current field strength limits of 47 CFR § 18.305 (b) for time domain terahertz instrumentation. TeraMetrix has no objections to raising the 47 CFR § 18.305 (b) field strength limits above 95 GHz above the current nom-ISM limits, but TeraMetrix does not believe that this is currently necessary. However there is no justification that these § 18.305 (b) limits should be reduced (TeraMetrix is not suggesting that the FCC is contemplating reducing these limits).

NPRM FCC 18-17 paragraph 62 further states:

"…We also seek comment on whether any other changes to the rules may be required to prevent harmful interference to authorized services. For example, should we restrict operation in certain frequency bands to indoor locations only, and if so, in which frequency bands should such a restriction apply and how could it be enforced?"

TeraMetrix observes that currently ISM devices that meet 47 CFR § 18.305 (b) emission limits outside of the ISM bands are not restricted to "certain frequency bands" (as the limits are already the constraints of minimum emission) and that there is no requirements that ISM

instrumentation operate in only indoor locations in the current Part 18 rule. TeraMetrix's time domain terahertz instrumentation has a working distance of usually less than 10 cm and in all cases less than 1 m. There is no application for time-domain terahertz where the emitters are pointed into free space – they always are pointing at a target that acts as shield. TeraMetrix notes that its time domain terahertz instrumentation meets the extremely low emission requirements below 95 GHz (which place no limit on its use); and that above 95 GHz the commission notes that the emitted RF is even more directional, attenuated by atmosphere, and shielded by most materials. Considering that outdoor RF interference below 95 GHz is more likely than outdoor interference above 95 GHz; it would seem burdensomely more restrictive to require indoor operation of time domain terahertz as long as the instrumentation meets existing 47 CFR § 18.305 (b) emission limits outside of the ISM bands.

In conclusion, TeraMetrix believes that 47 CFR Part 18 currently provides and adequate regulatory framework for the marketing and sale of time domain terahertz instrumentation by itself and other manufacturers.

Respectfully Submitted,

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